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Ten-Year Tests of Rapid-Hardening Portland Cement Concrete.

THE results of tests on specimens of concrete made with rapid-hardening Portland cement ten years previously are given in Research Paper No. 1508 of the United States National Bureau of Standards. The tests were made on 6in. by 12in. cylinders of concretes and mortars made with twelve different rapid-hardening Portland cements.

Cements, Mixes and Storage Conditions.

The chemical compositions and fineness values of the cements are given in Table 1. The concrete mix was 1 : 2·28 : 4·51 by weights of dry cement, sand and gravel respectively. The sand had a fineness modulus of 2·8. The gravel ranged

TABLE 1.
CHEMICAL COMPOSITIONS AND FINENESS VALUES OF CEMENTS.

Cement	Chemical compositions										Fineness	
	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	SO_3	Cl	Insoluble in HCl	Loss on ignition	Free CaO[a]	Retained on No. 325 sieve	Specific surface by Wagner turbidimeter
	%	%	%	%	%	%	%	%	%	%	%	cm^2/g
1	66.2	1.1	8.3	3.1	17.0	2.4	0.0	0.2	1.7	0.4	8.5	1,990
2	66.6	1.0	6.2	1.9	20.6	2.5	.0	.5	1.1	1.6	8.3	1,910
3[b]	65.6	2.5	4.7	3.1	20.6	1.3	.3	.5	2.4	0.3	8.8	1,770
4	65.7	2.5	5.6	2.3	19.3	2.2	.02	.6	2.1	2.7	8.7	2,030
5	64.2	3.4	7.2	2.5	18.5	2.4	.04	.2	1.8	0.6	5.3	1,760
6	62.9	2.9	7.0	2.3	20.3	2.6	.08	2.3	1.6	.1	8.4	2,050
7	65.7	1.5	6.6	2.7	19.3	2.1	.03	0.4	1.8	1.5	5.8	1,970
8	65.4	2.7	6.4	1.9	19.3	2.3	.0	.2	1.7	4.2	9.6	2,180
9	66.2	2.2	4.4	2.8	21.6	1.9	.0	.1	1.2	0.4	7.5	2,120
10	62.3	3.4	7.1	2.8	18.5	2.5	.0	.5	2.7	1.9	8.8	1,930
11	63.3	3.5	6.4	2.5	19.1	2.6	.07	.4	1.9	1.2	5.1	2,150
12	60.6	4.8	4.8	2.4	21.9	2.7	.0	.7	2.5	0.9	6.6	2,490

[a] By method of Emley, Trans. Am. Ceram. Soc. 17, 720 (1915).
[b] Contains a water-repellent material.

TABLE 2.—COMPRESSIVE STRENGTHS (LB. PER SQ. IN.) OF 6-IN. BY 12-IN. CONCRETE CYLINDERS.

Cement	C/W (by weight)	1 day	Subsequent storage condition: Damp air, 3 days	Damp air, 7 days	Damp air, 28 days	Damp air, 1 year	Damp air, 10 years	Laboratory air, 7 days	Laboratory air, 28 days	Laboratory air, 1 year	Laboratory air, 10 years	Outdoors, 1 year	Freezing and thawing, 300 cycles[a] in 15 months
STORED AT 70° F DURING FIRST 24 HOURS													
	1.73	1,470	3,100	3,430	3,840	3,880	4,230	3,170	3,930	4,190	4,280	3,020	3,890
1	1.50	1,120	1,880	2,830	3,240	2,780	2,810	2,480	3,390	3,140	3,790	2,930	3,430
	1.33	550	1,250	1,570	1,980	2,120	1,670	1,740	2,350	2,230	2,710	1,990	2,220
	1.73	1,150	2,610	3,510	4,340	6,140	5,140	3,210	3,900	4,090	4,370	4,110	4,950
2	1.50	760	2,200	2,600	3,620	4,850	4,240	2,570	2,890	2,950	3,550	3,070	3,950
	1.33	470	1,320	1,940	2,620	3,050	3,350	1,730	2,330	2,150	2,410	2,570	2,650
	1.73	990	2,220	3,010	3,690	4,490	5,020	2,930	3,660	3,150	3,560	3,860	4,120
3	1.50	620	1,590	2,050	2,520	3,660	4,050	2,050	3,010	2,450	2,650	3,030	3,660
	1.33	410	990	1,510	1,930	2,640	2,790	1,470	2,030	1,620	1,910	1,980	2,710
	1.73	1,190	2,940	3,900	4,310	5,340	6,270	4,020	4,660	4,320	4,780	4,970	5,010
4	1.50	760	2,360	3,030	3,720	3,910	4,480	2,880	3,960	3,010	3,700	3,990	4,310
	1.33	460	1,540	2,390	2,820	3,010	3,450	2,220	2,880	2,070	2,290	2,910	3,270
	1.73	1,160	3,080	3,810	4,880	5,240	5,350	3,270	4,600	4,370	4,630	5,100	5,010
5	1.50	770	2,200	2,800	3,840	4,150	4,110	2,470	3,740	3,400	3,680	4,470	3,600
	1.33	530	1,710	2,470	3,180	3,130	3,500	2,130	2,830	2,600	3,000	3,460	2,840
	1.73	900	2,480	3,470	4,520	6,370	6,050	3,050	4,030	4,280	4,940	4,970	5,340
6	1.50	560	1,750	2,630	3,650	5,110	5,440	2,200	3,140	3,080	3,890	4,340	4,370
	1.33	390	1,230	2,090	2,900	3,860	3,530	1,760	2,470	2,070	3,260	3,500	3,160
	1.73	1,320	3,090	4,370	5,100	6,410	6,120	3,710	4,360	3,970	5,450	5,560	4,900
7	1.50	950	2,330	3,600	4,300	5,200	4,970	2,810	3,530	3,290	4,420	4,670	4,210
	1.33	590	1,740	2,760	3,320	4,280	3,820	2,210	2,650	2,360	3,500	2,960	3,250
	1.73	1,320	2,670	4,070	5,100	5,910	6,370	3,550	4,370	4,290	5,490	5,300	5,700
8	1.50	840	2,090	3,320	4,100	4,380	5,090	2,720	3,410	3,490	4,160	4,960	4,510
	1.33	570	1,430	2,440	3,440	3,890	4,140	2,060	2,710	2,710	3,360	3,620	3,040
	1.73	1,150	2,780	3,940	5,560	5,800	7,290	4,150	4,830	4,300	4,380	4,730	5,470
9	1.50	820	2,590	3,050	4,930	5,190	5,810	2,570	3,550	3,050	3,850	4,340	4,970
	1.33	560	1,530	2,290	3,450	3,510	3,510	1,820	2,440	2,120	2,610	3,670	3,170
	1.73	1,040	2,410	2,860	4,190	4,800	6,060	2,690	3,760	3,790	4,100	5,400	4,580
10	1.50	700	1,770	2,210	3,500	4,300	4,700	2,190	2,850	2,720	3,350	4,110	4,090
	1.33	390	1,210	1,790	2,500	3,100	3,310	1,490	2,300	2,070	2,520	3,260	2,920
	1.73	1,520	2,940	4,400	5,130	5,810	6,340	3,750	4,920	4,920	5,860	5,770	5,600
11	1.50	1,070	2,120	3,440	3,770	4,780	5,150	2,870	3,480	3,570	4,400	4,570	4,600
	1.33	630	1,600	2,470	3,040	3,430	3,900	2,290	2,670	2,790	3,440	3,890	2,990
	1.73	1,090	2,420	3,390	4,640	6,130	7,310	3,080	3,960	4,230	5,330	6,320	5,660
12	1.50	820	1,680	2,540	3,990	5,020	5,150	2,310	2,890	3,070	4,310	5,310	5,200
	1.33	560	1,230	1,790	2,770	3,660	4,470	1,650	2,200	2,250	3,960	4,320	3,490
STORED AT 90° F DURING FIRST 24 HOURS													
	1.73	2,150	2,760	3,330	3,100	3,650	4,230	3,280	3,780	3,880	4,510	3,820	3,750
1	1.50	2,000	2,600	3,010	2,880	3,140	3,230	2,560	3,050	2,990	3,240	2,710	2,870
	1.33	1,280	1,520	1,810	1,930	2,100	2,240	1,920	2,310	2,400	2,640	1,990	2,090
	1.73	1,940	2,760	3,350	3,750	5,070	5,610	3,350	2,850	3,940	4,250	4,450	4,710
2	1.50	1,380	2,050	2,780	2,930	3,690	4,430	2,510	3,450	2,920	3,580	3,670	4,130
	1.33	890	1,320	1,680	2,140	2,880	3,200	1,640	2,640	2,180	2,650	2,850	2,770
	1.73	1,780	2,450	2,860	3,790	4,310	5,180	2,800	3,720	3,280	3,710	4,520	3,960
3	1.50	1,140	1,540	1,890	2,800	3,290	3,730	2,040	2,680	2,490	2,770	3,430	3,250
	1.33	700	1,020	1,290	2,010	2,280	2,830	1,150	1,660	1,500	1,880	2,200	2,810
	1.73	2,180	3,060	3,750	4,590	5,150	5,670	3,460	4,270	4,160	4,350	5,340	4,870
4	1.50	1,540	2,230	2,610	3,270	3,640	4,530	2,800	3,020	2,730	3,300	3,880	3,800
	1.33	1,100	1,790	1,770	2,640	2,720	3,430	1,960	2,350	1,930	2,720	2,610	2,660
	1.73	1,990	2,840	3,390	4,140	4,260	5,210	2,750	4,160	4,210	4,400	4,790	4,340
5	1.50	1,410	2,100	2,740	3,260	3,570	3,860	2,690	3,230	2,950	3,330	4,210	3,690
	1.33	960	1,750	2,030	2,560	3,170	3,080	2,090	2,480	2,180	2,540	3,410	2,770
	1.73	1,520	2,840	3,540	4,650	5,830	6,270	3,300	4,700	4,600	4,860	4,680	4,760
6	1.50	1,150	1,890	2,540	3,570	4,850	5,060	2,390	3,380	3,120	3,880	4,330	4,320
	1.33	770	1,460	2,090	3,000	3,990	3,890	2,000	2,600	2,310	3,140	3,570	3,680
	1.73	2,210	3,180	4,310	4,000	4,800	5,310	4,030	4,200	4,080	5,660	4,990	4,650
7	1.50	1,630	2,470	3,390	3,920	4,320	4,620	3,290	3,770	3,570	4,590	4,640	4,190
	1.33	1,130	1,760	2,410	2,950	3,490	3,790	2,250	2,370	1,960	3,380	3,120	3,360
	1.73	2,000	3,190	3,600	4,690	5,210	6,210	3,660	4,480	4,260	5,350	5,520	4,890
8	1.50	1,440	2,140	2,680	3,810	4,520	5,370	2,670	3,430	3,200	3,940	4,250	4,210
	1.33	970	1,560	2,460	3,220	3,340	3,930	2,110	2,470	2,450	3,290	3,300	3,340
	1.73	2,430	3,560	4,100	4,840	6,000	6,120	3,880	4,850	4,120	4,940	6,100	5,380
9	1.50	1,570	2,310	2,920	3,880	4,010	4,610	2,830	3,350	3,000	3,910	4,570	4,350
	1.33	1,060	1,610	2,260	2,700	3,400	3,560	2,030	2,600	2,020	2,600	3,540	3,050
	1.73	1,590	2,160	3,050	3,670	5,170	5,680	2,890	3,650	3,790	4,510	4,840	4,230
10	1.50	1,240	1,800	2,140	2,990	4,040	4,560	1,970	2,710	2,810	3,410	4,100	3,830
	1.33	710	1,160	1,330	2,430	2,990	3,240	1,430	1,980	2,010	2,330	2,990	3,140
	1.73	2,230	3,610	3,750	5,300	5,980	6,560	3,930	4,910	4,790	5,510	5,390	5,510
11	1.50	1,560	2,360	3,070	3,980	5,050	5,040	2,900	3,760	3,370	4,390	4,580	4,420
	1.33	890	1,440	2,220	2,620	3,450	3,570	1,950	2,730	2,580	3,400	3,650	3,060
	1.73	1,810	2,070	3,060	4,670	6,240	6,770	3,320	4,000	4,260	5,310	6,020	5,260
12	1.50	1,160	1,890	2,350	3,020	4,700	5,200	2,120	2,890	3,170	4,120	4,640	4,530
	1.33	760	1,200	1,670	2,460	3,480	3,890	1,480	2,430	2,230	3,300	3,540	3,660

[a] Freezing in air at 5° to 20° F, 16 hours; thawing in water at about 70° F, 8 hours.

TABLE 2 (continued).—COMPRESSIVE STRENGTHS (LB. PER SQ. IN.) OF 6-IN. BY 12-IN. CONCRETE CYLINDERS.

Cement	C/W (by weight)	1 day	Subsequent storage condition: Damp air					Laboratory air				Outdoors	Freezing and thawing
			3 days	7 days	28 days	1 year	10 years	7 days	28 days	1 year	10 years	1 year	300 cycles[a] in 15 months
STORED AT 110° F DURING FIRST 24 HOURS													
	[b]1.73	1,620	2,080	2,350	2,350	3,420	2,920	2,170	2,430	3,050	3,190	3,380	3,460
1	1.50	1,780	2,190	2,680	3,100	3,550	3,220	2,310	2,910	2,960	3,210	3,540	3,490
	1.33	1,410	1,800	2,090	2,200	2,630	2,490	1,980	2,290	2,140	2,460	2,430	2,580
	1.73	2,330	2,980	2,980	3,020	4,890	5,270	3,320	3,660	3,890	4,320	4,040	4,450
2	1.50	1,610	2,110	2,550	2,670	4,100	4,200	2,440	3,140	2,690	3,730	3,520	3,770
	1.33	1,480	1,630	1,960	2,120	3,540	3,350	2,060	2,220	2,180	2,890	2,910	2,960
	1.73	2,470	3,010	3,360	3,520	4,610	5,170	3,490	4,160	4,080	4,460	4,570	4,810
3	1.50	1,650	2,440	2,630	2,710	3,750	4,410	2,420	2,810	2,940	3,220	3,740	3,610
	1.33	1,250	1,550	1,910	2,090	2,640	3,280	1,710	2,220	2,060	2,470	2,750	3,100
	1.73	2,360	2,490	3,070	4,390	4,380	5,800	3,540	4,090	3,830	4,460	5,560	3,930
4	1.50	1,900	2,290	2,540	3,420	3,980	4,520	2,720	3,680	3,250	3,290	4,120	3,870
	1.33	1,430	1,810	2,150	2,330	3,170	3,040	2,020	2,920	2,320	2,850	3,480	3,340
	1.73	2,300	2,850	2,720	3,530	3,760	4,570	2,620	3,580	3,380	3,610	3,500	3,420
5	1.50	1,660	2,130	2,430	3,010	3,520	4,280	2,560	3,010	3,120	3,360	4,020	3,570
	1.33	1,240	1,560	1,900	2,480	2,980	3,480	1,740	2,410	2,410	2,760	3,760	3,050
	[b]1.73	1,640	1,530	2,240	3,070	3,460	4,100	3,170	2,910	2,840	4,110	4,390	3,250
6	1.50	1,740	2,280	2,700	3,390	4,650	5,120	2,600	3,480	3,040	4,020	4,190	4,200
	1.33	1,250	1,840	2,170	3,030	4,250	4,600	2,120	2,610	2,320	3,110	3,630	3,780
	[b]1.73	1,690	2,490	2,580	2,740	3,070	3,680	2,410	4,140	3,740	4,990	3,310	3,020
7	1.50	2,240	2,850	3,360	3,840	4,970	4,780	3,260	3,870	3,390	4,000	4,390	3,860
	1.33	1,600	2,120	2,690	3,140	4,010	3,930	2,530	2,930	2,650	3,270	3,480	3,420
	[b]1.73	2,010	1,650	2,560	3,580	4,650	4,120	3,220	3,300	3,430	5,080	5,080	3,160
8	1.50	1,970	2,170	3,010	3,760	4,470	4,980	3,050	3,730	3,710	4,600	4,680	4,180
	1.33	1,460	1,960	2,230	3,160	3,740	4,090	2,380	2,780	3,000	3,580	3,830	3,360
	1.73	2,680	3,680	4,010	4,980	5,330	6,580	3,880	4,930	4,710	5,290	6,140	5,320
9	1.50	2,290	2,840	3,500	3,650	4,580	4,890	3,500	3,910	3,750	4,380	5,840	4,550
	1.33	1,620	2,320	2,750	3,400	4,060	4,020	2,880	3,220	2,830	3,220	4,130	3,220
	1.73	1,760	2,060	2,690	3,180	3,960	5,300	2,770	3,220	3,600	4,590	4,490	3,700
10	1.50	1,650	1,770	2,170	2,560	3,330	4,200	2,140	2,730	3,210	3,120	4,110	3,470
	1.33	1,020	1,370	1,610	2,070	2,770	3,510	1,440	2,020	2,190	2,560	3,240	2,330
	1.73	2,900	3,160	3,870	4,940	5,520	6,360	3,980	4,730	4,350	6,030	5,470	3,910
11	1.50	2,080	2,670	3,340	3,900	4,760	5,060	3,770	3,670	3,820	4,300	4,290	4,230
	1.33	1,520	2,100	2,420	3,180	3,540	3,850	2,380	2,940	2,810	3,620	3,600	3,450
	[b]1.73	1,330	1,600	1,940	2,470	4,340	4,780	2,110	2,690	2,750	4,530	3,560	3,200
12	1.50	1,560	2,100	2,310	3,570	5,180	5,580	2,570	3,210	3,590	4,590	5,450	4,480
	1.33	1,030	1,470	1,880	2,890	4,070	4,670	2,020	2,560	2,700	3,500	4,430	3,680
INSULATED DURING FIRST 24 HOURS													
	1.73	2,380	2,880	3,140	3,480	3,500	4,260	3,120	3,890	3,820	4,210	3,420	3,790
1	1.50	1,800	2,100	2,430	2,660	2,720	3,200	2,550	3,890	2,930	3,630	2,420	3,320
	1.33	1,070	1,490	1,510	1,970	2,090	2,130	1,740	2,100	2,180	2,440	1,830	2,150
	1.73	1,690	2,600	3,160	3,470	4,430	5,380	3,080	3,620	3,710	4,160	4,170	4,210
2	1.50	1,260	2,070	2,120	2,890	3,140	4,020	2,080	2,510	2,420	3,170	3,520	3,380
	1.33	820	1,430	1,730	1,930	2,340	2,930	1,470	1,770	1,600	2,650	2,340	2,530
	1.76	1,270	1,990	2,430	3,020	4,140	4,830	2,670	3,060	2,670	3,590	3,860	4,210
3	1.50	830	1,400	1,540	2,130	3,040	4,040	1,640	1,980	1,750	2,540	2,870	3,540
	1.33	480	860	1,140	1,610	2,160	2,720	1,030	1,650	1,190	1,810	2,090	2,570
	1.73	2,150	3,010	3,280	3,700	4,270	5,340	3,180	3,850	3,730	4,160	4,510	4,450
4	1.50	1,180	2,080	2,590	3,230	3,560	4,440	2,640	2,780	2,560	3,440	4,010	3,680
	1.33	870	1,610	1,860	2,580	2,760	3,370	2,080	2,510	1,800	2,380	2,660	2,830
	1.73	1,600	2,790	2,910	3,590	4,240	4,660	3,080	3,690	3,620	4,300	5,090	4,510
5	1.50	1,280	2,020	2,760	3,050	3,300	3,720	2,430	3,200	2,740	3,330	4,030	3,820
	1.33	830	1,670	2,200	2,480	2,690	3,040	1,880	2,550	2,080	2,700	3,320	2,710
	1.73	1,350	2,460	3,030	3,590	4,990	5,840	2,930	3,580	3,530	4,810	4,680	4,990
6	1.50	1,000	1,950	2,420	3,400	3,890	4,790	2,300	2,910	2,530	3,930	4,160	4,130
	1.33	640	1,140	1,910	2,600	3,000	3,440	1,650	2,070	2,050	2,870	3,000	3,090
	1.73	2,040	3,100	3,850	4,160	5,180	5,850	3,800	4,370	4,050	5,610	4,650	4,960
7	1.50	1,470	2,300	3,150	4,000	4,080	4,610	2,790	3,380	2,940	4,210	4,440	3,360
	1.33	1,020	1,730	1,600	2,070	2,120	2,510	2,180	2,660	2,030	3,300	3,230	3,180
	1.73	1,870	2,670	3,450	3,840	4,820	5,810	3,150	4,460	3,840	5,330	5,600	4,810
8	1.50	1,270	2,050	3,340	3,820	3,720	4,740	2,120	3,350	3,050	4,130	4,350	3,900
	1.33	910	1,710	2,290	3,170	3,160	3,860	1,950	2,710	2,350	3,300	3,800	2,470
	1.73	2,120	3,350	3,640	4,210	4,290	5,970	3,720	4,560	3,320	5,050	5,460	5,390
9	1.50	1,030	2,070	3,130	3,800	4,480	5,240	2,240	3,240	2,960	3,780	4,420	4,620
	1.33	660	1,420	2,110	2,970	3,370	3,240	1,750	2,430	1,730	2,670	3,090	3,350
	1.73	1,420	1,920	2,810	2,930	4,280	5,300	2,240	3,200	3,150	3,880	4,420	4,450
10	1.50	940	1,560	1,870	2,530	3,460	4,240	1,770	2,640	2,240	3,010	3,370	3,030
	1.33	660	1,110	1,340	2,250	2,610	3,200	1,370	1,750	1,680	2,080	2,660	2,260
	1.73	1,930	2,850	3,590	4,010	4,590	5,800	3,610	3,950	3,670	4,860	4,770	5,110
11	1.50	1,250	1,930	2,770	3,520	4,090	4,750	2,170	3,090	2,970	3,790	3,940	4,130
	1.33	700	1,280	1,920	2,460	2,610	3,360	1,740	2,670	2,140	2,900	3,050	3,120
	1.73	1,310	2,130	2,960	4,240	5,460	6,560	2,450	3,850	3,890	5,120	4,860	5,040
12	1.50	940	1,520	2,200	3,340	4,320	5,280	1,920	3,080	3,200	4,160	4,170	4,000
	1.33	580	1,140	1,650	2,910	3,430	3,870	1,410	1,740	1,930	3,480	3,350	3,280

[a] Freezing in air at 5° to 20° F, 16 hours; thawing in water at about 70° F, 8 hours.
[b] Cylinders for this cement, made at 110° F, C/W=1.73, were honeycombed.

from ¼in. to 1in. in size. Concretes of three cement-water ratios were tested, namely 1·73, 1·50 and 1·33 by weight, corresponding to 6·5, 7·5 and 8·5 United States gallons of water per 94-lb. bag of cement.

The temperatures of the materials at the time of mixing, and the conditions of storage of the test specimens during the first 24 hours after moulding, were as follows: (1) Mixed at 70 deg. F., stored in air at 70 deg. F.; (2) Mixed at 90 deg. F., stored in air at 90 deg. F.; (3) Mixed at 110 deg. F., stored in air at 110 deg. F.; (4) Mixed at 70 deg. F., stored in a thermally insulated cabinet; (5) Mixed at 70 deg. F., stored adiabatically (no heat loss). No 10-year specimens were made for the adiabatic storage.

After the first 24 hours specimens from each of the other four initial conditions were treated as follows until tested: (1) Stored in damp room at 70 deg. F., at relative humidity over 95 per cent.; (2) Stored in air of laboratory at 70 deg. F.; (3) Stored outdoors for one year; (4) Subjected to 300 cycles of freezing and thawing in approximately 15 months. Specimens of only the first two of these storage conditions remained for 10-year tests.

Test Results.

The compressive strengths of concretes made from each cement are given in Table 2 for ages from one day up to ten years. Each value is the average for a set of three cylinders. The maximum deviation from the average was generally less than 10 per cent. Age-strength relations for two of the cements (Nos. 7 and 11), representing typical variations, are shown in Figs. 1 and 2.

The concretes which were damp-cured showed continued increase in strength, in most cases between one year and ten years; such gains were of about the same magnitude as those between 28 days and one year. In a few instances, concretes stored at 70 deg. F. during the first 24 hours showed slight decreases in strength between one year and ten years, but in such cases the strengths remained practically equal to those of the concretes which were initially stored at higher temperatures or were thermally insulated. Though the 1-day strengths were higher when the concretes were stored at the higher temperatures during the first 24 hours, the strengths at later ages tend to equalise. There is, however, some tendency for the initially insulated concretes to have somewhat lower strengths after three days and up to ten years than those under the other conditions.

The concretes in laboratory air storage also show a slight gain in strength between one year and ten years, but this gain is often just sufficient to compensate for the frequently noted slight decrease in strength between 28 days and one year, so that generally the air-stored concretes are appreciably lower in strength at ten years than those damp-cured.

It is of some interest to compare the strengths of the concretes of this investigation with those obtained by Withey (Proceedings of the American Concrete Institute, 27, 547, 1931) for water-cured concretes made in 1910, and those of the P.C.A. 1926 series cited by him. Such a comparison is made in Table 3. In order to make this comparison on an equal cement-water basis it

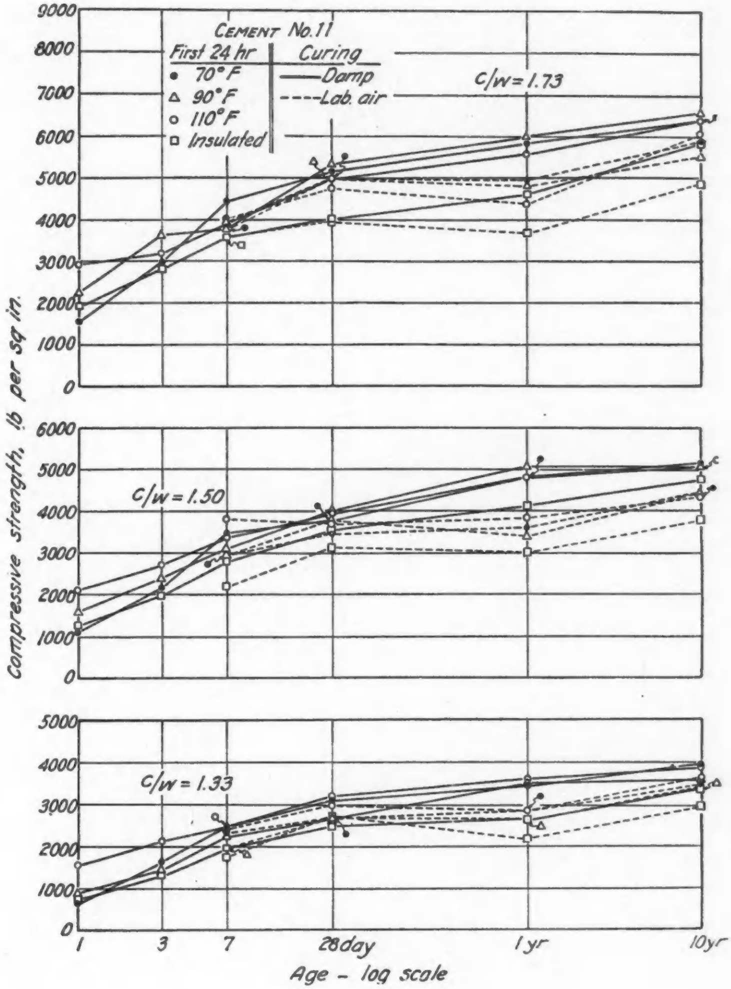

Fig. 1.—Age-strength relations for Cement No. 11.

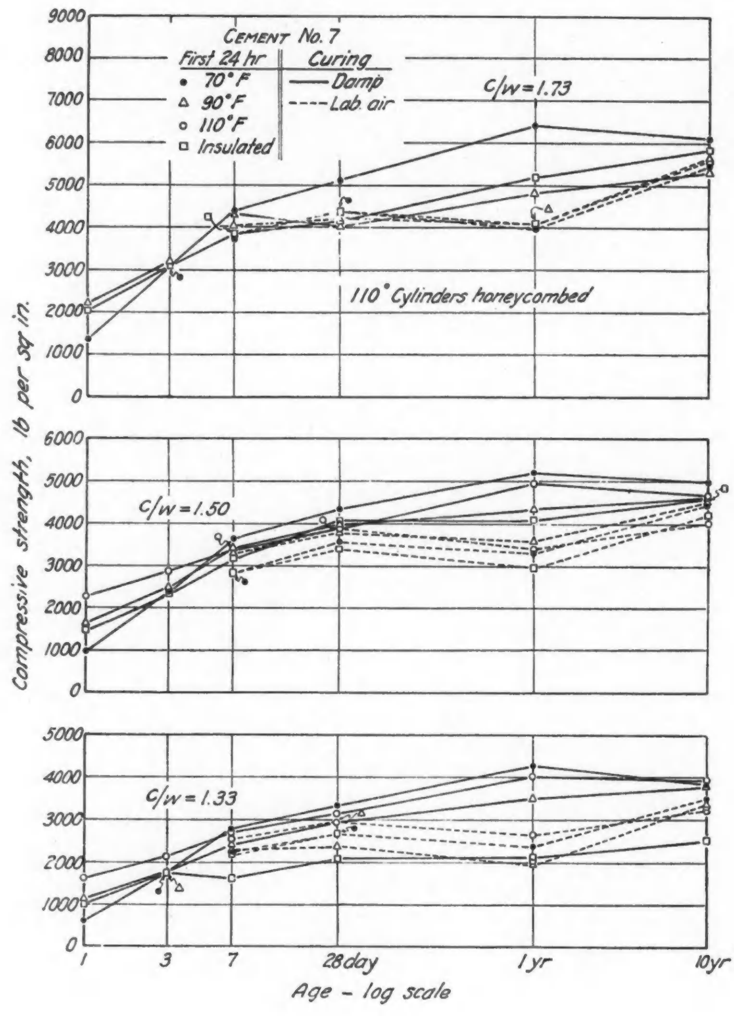

Fig. 2.—Age-strength relations for Cement No. 7.

TABLE 3.—COMPRESSIVE STRENGTHS OF 1 : 6 CONCRETES (LB. PER SQ. IN.).

Age when tested				Source of data	C/W (by weight)
1 day	1 mo	1 yr	10 yr		
....	2,000	3,200	4,200	Withey, series A, 1910 [a]	1.60
....	3,000	5,000	....	PCA, 1926	1.60
970	4,100	5,000	5,300	NBS 1929-32, 12 high-early-strength cements	[b] 1.60
....	4,600	5,900	....	NBS 1941, 5 normal cements	1.66
1,060	5,700	5,700	....	NBS 1941, 3 high-early-strength cements	1.66
....	4,250	6,300	....	NBS 1941, 4 moderate-heat cements	1.66

[a] 6- by 18-in. cylinders.
[b] Interpolated from values for $C/W = 1.73$ and 1.50.

was necessary to interpolate the strength values for a cement-water ratio of 1 : 60 between those for cement-water ratios of 1 : 73 and 1 : 50. The average strengths of the twelve cements for the 70 deg. F. initial damp-cured concretes were used. In addition, some values recently obtained at the Bureau for various types of cement made in 1941 are included.

It is seen that the more recent cements (1941), even of the moderate-heat type, attain strengths in one month about equal to those for the 1910 cement at ten years. Similarly, the high-early-strength cements of 1941 gave strengths at one month exceeding those of the 1929–32 cements of this type at ten years. The 1941 high-early-strength cements also showed appreciably higher 3-day and 7-day strengths than those for the 1929–1932 cements, though the 1-day strengths were not appreciably greater.

Explosives Used in Quarries.

THE Ministry of Fuel and Power announces that further changes will shortly be made affecting the supply of blasting explosives used in mines and quarries.

The explosives which will continue to be available are as follows : *Section A* (*i*) Nitroglycerine explosives, gelatinous type—Antifrost Gelammonite No. 3 (S), Antifrost Nitrox No. 3 (S), Driftex (S), Plastex (S), Polar Ajax (S), Polar Saxonite No. 3 (S). *Section A* (*ii*) Nitroglycerine explosives, powdery type—Antifrost Penrhyn Power (S), Antifrost Penrhyn Power No. 2 (S), Bettacol (S), Colex No. 1 (S), Colex No. 2 (S), Dunelmite (S), Eversoft Seamex (S), Eversoft Tees powder (S), Polar Dynobel No. 2 (S), Polar Thames powder (S), Polar Viking (S), Simex No. 3 (S), Wincoal Extra (S). *Section B* Non-nitroglycerine explosives—Ammonite No. 1P, Celmonite, Denaby powdery No. 2 (S), Douglas powder (S), Gathurst powder, Hawkite No. 2 (S), Hawkite No. 3 (S), Norsabite (S), Tuthilite, XL. Hawkite (S).

The following are the diameters and weights of blasting cartridges now available : *Permitted explosives*—A (i) Nitroglycerine explosives, gelatinous type, $\frac{7}{8}$ in., $1\frac{1}{4}$in., and $1\frac{7}{16}$in. ; ten to 1 lb. (unsheathed only) ; 2, 3, 4 and 6 oz. (sheathed or unsheathed) ; 8 oz. to order. A (ii) Nitroglycerine explosives, powdery type, and non-nitroglycerine explosives, $1\frac{1}{4}$in. and $1\frac{7}{16}$in. ; 2, 3, 4 and 6 oz. (sheathed or unsheathed) ; 8 oz. to order. *Other explosives*—$\frac{7}{8}$in., 10 to 1 lb. ; $1\frac{1}{8}$in., $1\frac{1}{4}$in., $1\frac{5}{8}$ in., $1\frac{7}{16}$ in., $1\frac{3}{4}$ in., 2in. (Larger and heavier cartridges for special purposes supplied to order.)

Carrying Cement in Bulk.

FROM May, 1942, to January, 1943, the Ministry of Works delivered 210,000 tons of cement in bulk to 34 contracts, thus saving 1,400 tons of paper and much time and labour compared with the usual method of packing in paper bags. Before the war cement was packed in paper for most inland deliveries. When paper became difficult to obtain, jute sacks were also used. In March, 1942, more than 50 per cent. of the packing of cement was done in jute sacks, but handling, drying, cleaning, and repairing them added considerably to the cost. A further incentive to bulk delivery was that packing plants were acting as a bottle-neck between production and delivery.

Towards the end of 1941 the Ministry obtained details of plant (and in particular Fuller Kinyon pumps) for handling cement in bulk and considered the

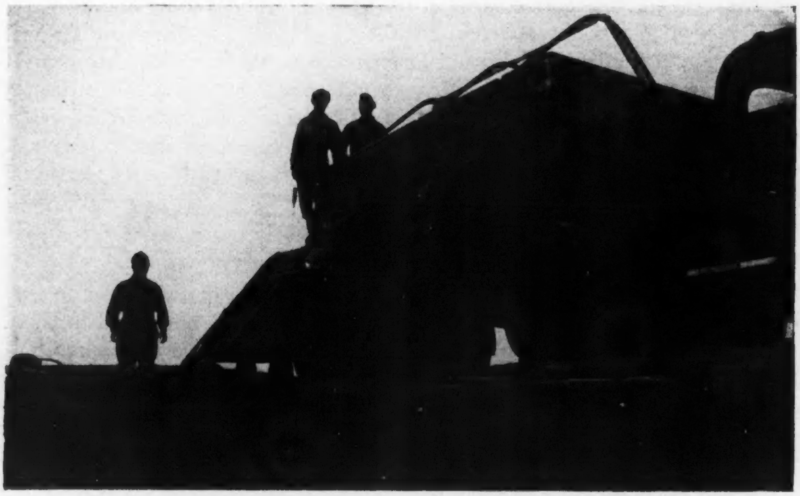

Fig. 1.—Delivering 12-ton Loads of Cement in Bulk.

transport of cement in bulk. The difficulty of obtaining Fuller Kinyon pumps from America and maintaining the necessary supply of spares demanded the improvisation of a suitable method. At this time no tipping lorries were obtainable. There were, however, a few 12-ton International articulated chassis available and it was decided to start with twelve steel tank bodies mounted on these chassis.

The flow of cement varies according to its temperature, to whether it is loaded by air or gravity, whether it is from " dead " or " live " silos, and to the type of road over which the load has travelled. It was decided therefore to design a light steel body which would remain permanently on the chassis and to abandon the idea of return loads. The lorry door had to be large enough to obtain a fast

but controlled discharge, and small enough not to preclude the fitting of cement-tight joints which would stand up to bad handling on rough roads. For these 12-ton lorries four doors, approximately 18in. by 9in. each, sealed with canvas strips, were arranged at the side of the lorry. As the regular supply of loads fast enough to keep big central mixing plants working on aerodrome work was uncertain it was decided to establish storage capacity at the receiving end to provide against delays or breakdowns of the lorries. A receiving shed was erected, in which were two brick bins holding about thirty tons of cement, delivering to the boot of an elevator driven by an independent oil engine and so delivering into the worm gear of a continuous concrete mixer. To discharge into the bins, the

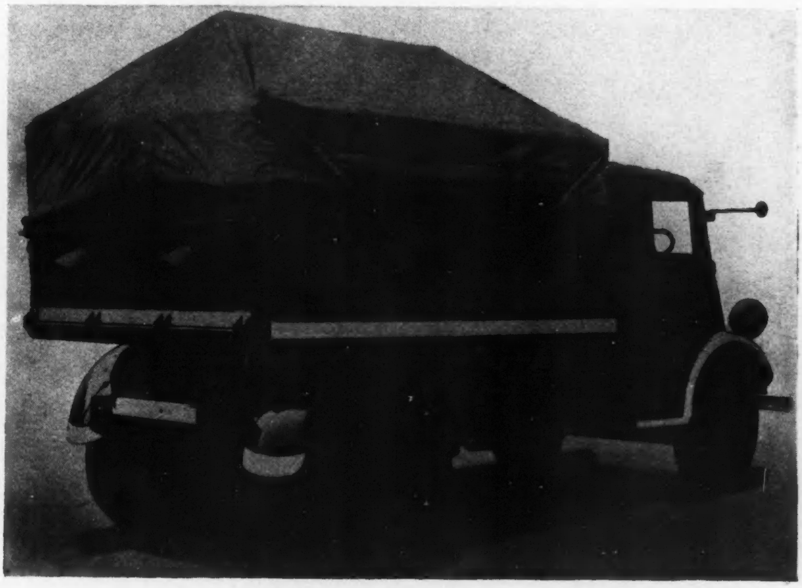

Fig. 2.—5-ton Tipping Lorries for Delivering Cement in Bulk.

lorry was run up a ramp, and guided into position by concrete kerbs. The lorry carried four unloading chutes which hooked on to the doors and the lorry could be emptied in twenty minutes by four men.

This system worked well, but it was found to be more practical to run the lorries up a ramp and feed the mixer by gravity. By this method the quantity delivered varies from 3,000 to 6,000 tons per week, and five or six men per concrete mixer are freed for other work, apart from the labour and time involved in counting and checking sacks for return. These ramps can be built in two or three days with a dragline.

After the 12-ton lorries had been running for two or three months, 125 5-ton short-chassis Fords were obtained—90 tippers and 30 tank bodies fitted with doors interchangeable with those on the 12-ton Internationals already running and with the unloading chutes which had been designed for them. The tipping bodies were operated by a standard Anthony hoist with 9in. depth added to take the load, fitted with tarpaulin covers and a cam-action tailboard fitted with rubber joints. In the tailboard were built two 6in. feed valves with a sliding steel cut-off, and on which could be clipped a canvas trunk. In this way the same lorry can give a full tip directly into the hopper of a central concrete mixer or a controlled feed into a continuous mixer. The 6in. feed valve was found to be too small, and for the next batch of sixty lorries the size of the valve was increased to 9in.

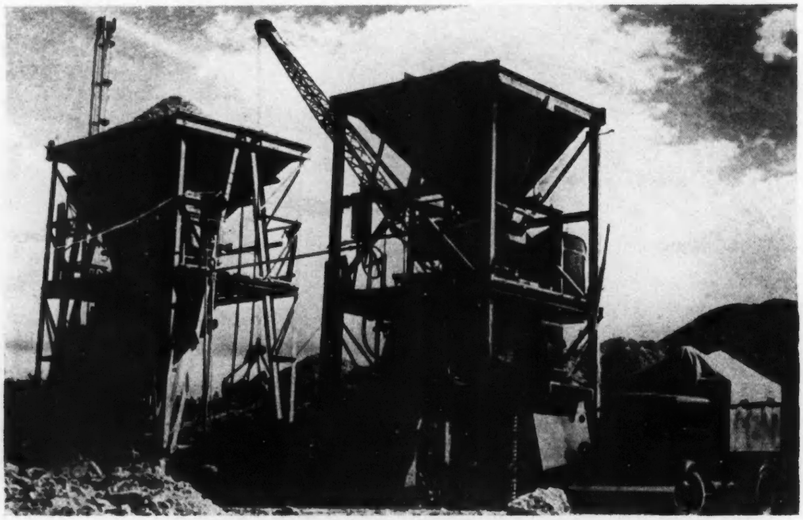

Fig. 3.—Concrete Batching Plant on Aerodrome Construction Supplied by Cement Delivered in Bulk.

It was evident that cement would have to be delivered in bulk by rail to jobs which were beyond the economic range of the lorries, and railheads were erected at certain points. A number of railway trucks were sheeted and made cement-tight and for one of these jobs 50-ton steel railway wagons which had been carrying chemical products were obtained. The cement was taken in these trucks direct from the cement works to the railheads, where a transfer shed was erected and a number of cement lorries travelled between the railhead and the site. Owing to the difficulty of obtaining conveying plant it was decided to empty the railway trucks on to a concrete floor and load the cement from there into lorries by means of a standard Muirhill shovel. In one or two cases bulk conveyors were

tried, but they were neither fast nor reliable enough. The shovels worked satisfactorily, and one railhead alone has handled nearly 10,000 tons in this way at the rate of 120 to 180 tons a day.

In the construction of aerodrome runways, Ransome 34E, Multi-foot, and Rex pavers have been used incorporating a double-drum one-yard mixer. The Ransome 34E has worked at one mix taking 5 cwt. of cement every thirty seconds. This machine once poured 5,800 ft. on a 15ft. strip in one day. All the cement for this paver was supplied in bulk from two works situated 25 and 35 miles away. The machine was supplied with aggregate from a stockpile by means of a Muirhill dumper, and the cement in bulk was loaded on top of the ballast in the dumper from the 12-ton bulk-cement lorries, run on to a wooden ramp which was hauled to new positions by a bulldozer. Between the unloading chute of the cement lorry and the ballast in the Muirhill dumpers, two jubilee wagons without wheels were mounted in parallel. These were calibrated at 5 cwt., and after filling from the cement lorry were tipped alternately into dumpers running underneath.

Cement and Aggregate Mixtures Sold in Bags.

Under the trade name "Sakrete," a series of different mixtures of cement and aggregate seem to be meeting a demand in Cincinnati, Ohio. The mixtures are sold in paper bags in quantities of 90 lb. and 45 lb. The range of mixtures comprises cement and aggregates of various maximum sizes designed for a strength of 4,000 lb. per square inch at 28 days; cement and sand for rendering; cement and sand for mortar; and cement and aggregate mixtures containing waterproofing materials and hardening materials for use in floor toppings. The tops of the bags are sewn, as it was not found to be practicable to fill large aggregate into valve bags. The aggregates are thoroughly dried before they are mixed with the cement and filled into the bags, and it is found that the contents of each bag have to be mixed separately due to the segregation of materials encountered when large batches of mixtures containing large aggregate were mixed dry.

Apart from sales to private residents for use in the garden and elsewhere about the house, public utility corporations and those responsible for maintenance are finding a use for the material in carrying out small jobs, as it avoids the transport of separate materials and dry mixing on the site. An example quoted is a gas undertaking which has maintenance men travelling up to forty miles a day and using mortar or concrete at different places where they have disturbed a road or pavement. When the gangs took their materials separately and mixed them dry on the site it was usual for each maintenance gang to do eight or ten repairs a day. Now, by carrying ready-mixed materials, the number of repair jobs done per day is doubled, due to the time saved in unloading materials, dry mixing on the site, and returning unused materials to the lorry. Builders, also, are finding a use for the material for small jobs in inaccessible positions.

Determining Magnesia in Portland Cement.

Two methods for the rapid determination of magnesia in Portland cement which have recently been adopted as "Alternative Methods" by the American Society for Testing Materials are discussed by Mr. J. L. Heitzman in *Rock Products* for December, 1942.

The method whereby the magnesia is precipitated by 8-hydroxyquinoline and subsequently titrated against N/10 sodium thiosulphate may, the author states, be used with equal facility in the analysis of cement rock, limestone, quicklime, hydrated lime, clay, and similar materials. In a study of the applicability of this method it was found that the sodium chloride resulting from the fusion of siliceous materials with sodium carbonate and subsequent solution in dilute hydrochloric acid does not interfere with the accuracy of the determination. The method differs from that outlined by Redmond and Bright and J. C. Redmond only in that the magnesium quinolate is precipitated in the filtrate from the calcium oxalate. This enables the analyst to continue with the solution of the sample from which the silica, ferric oxide, alumina, and calcium oxide have been removed and determined, and the purpose is to shorten the time required for this determination which at present, with the use of the ammonium phosphate as the precipitant, requires from 24 to 36 hours. With the quinolate method the determination is easily completed within two hours. The solutions required are as follows :—

8-hydroxy-quinolate (1·25 per cent. solution).—Dissolve 25 gr. of 8-hydroxy-quinolate in 60 ml. of glacial acetic acid and dilute to two litres with distilled water. One ml. is equivalent to 0·0016 gr. MgO.

Sodium thiosulphate (0·1 normal).—Dissolve 25 gr. of sodium thiosulphate in 200 ml. distilled water and dilute to 1 litre. Standardise against re-sublimed iodine, arsenious acid, sodium oxalate, or other accurate method. Where many determinations are made it is more convenient to make an 8-litre solution. One ml. of N/10 sodium thiosulphate is equivalent to 0·000504 gr. MgO.

Potassium bromate-bromide (0·2 normal).—Dissolve 20 gr. of potassium bromide and 5·57 gr. of potassium bromate in 200 ml. of distilled water and dilute to 1 litre. Obtain to the sodium thiosulphate equivalent of this solution as follows : To 200 ml. of water in a 400-ml. beaker, pipette exactly 25 ml. of the bromate-bromide solution. Add 20 ml. of concentrated HCl and 10 ml. of 25 per cent. potassium iodide solution and titrate against the N/10 sodium thiosulphate until nearly colourless. Add 2 ml. of starch solution and continue the titration to the disappearance of the blue colour. Record the number of ml. of sodium thiosulphate for reference.

Potassium iodide (25 per cent. solution).—Dissolve 125 gr. of the salt in water and dilute to 500 ml.

Starch solution.—To 500 ml. of boiling water add a cold suspension of 5 gr. of soluble starch in 25 ml. of water. Cool, add 50 ml. of 100 per cent. sodium hydrate solution and 15 gr. of potassium iodide, and shake thoroughly.

Depending on the nature of the substance under examination it is brought into solution by fusion with sodium carbonate or solution in hydrochloric acid; ammonium chloride and hydrochloric acid or perchloric acid, and the silica, ferric oxide, alumina, and lime are removed and determined in the usual way.

The MgO content may be obtained by adding together the percentages of silica, ferric oxide, alumina, and lime, and subtracting from 100, unless the alkalis are present in appreciable amounts. In any event, the experienced analyst can fairly estimate the amount of MgO present. If the MgO is less than 5 per cent. the filtrate from the calcium oxalate is concentrated to 200 to 250 ml. If the MgO exceeds 5 per cent. the filtrate is cooled to room temperature and diluted to a definite volume and an aliquot portion is taken for the determination. Thus, for from 5 per cent. to 10 per cent. MgO the filtrate may be diluted to 500 ml. and 250 ml. of this taken for the determination. Best results are obtained if the aliquot portion taken contains from 3 per cent. to 5 per cent. of MgO. With dolomitic limestone, quicklime, or hydrated lime, the author found that by diluting the filtrate to 500 ml. and taking an aliquot portion of 50 ml. satisfactory results were obtained.

The concentrated filtrate or aliquot portion diluted to 200 to 250 ml. is brought to a temperature of 70 deg. C.; 20 ml. of the quinolate solution and 8 to 10 ml. (4 ml. to each 100 ml. of solution) NH_4OH is added and the solution is stirred two or three minutes with a rubber-tipped glass rod. The author has found no advantage in stirring for 15 minutes on a stirring machine. Indeed, unless it is closely watched, stirring on a machine may result in losses.

The precipitate is allowed to settle for about 15 minutes and is then filtered and washed five times with hot diluted ammonia (25 ml. concentrated ammonia hydroxide per litre of water). The filtrate is removed and discarded and the quinolate precipitate is dissolved with about 75 ml. of hot 10 per cent. HCl. The filter paper is thoroughly washed with cold water, the solution is diluted to 200 ml. and 15 ml. of concentrated HCl is added. The solution is then cooled to room temperature; 25 ml. of bromate-bromide solution is added and the solution is stirred; about 30 seconds are allowed for bromination. Add 10 ml. of 25 per cent. potassium iodide and titrate at once with the standard sodium thiosulphate solution. Since a 0·5-gr. sample is usually taken in analyses of this nature, the MgO is calculated as follows:

$$\%\ \text{MgO} - 200\ (A\text{-}B) \times C$$

where A = ml. of sodium thiosulphate solution equivalent to 25 ml. of the bromate-bromide solution; B = ml. of sodium thiosulphate solution required for the sample; and C = Wt. in gr. of MgO per ml. of the sodium thiosulphate solution.

It should be borne in mind that when an aliquot portion of the filtrate was taken the calculation must be modified to meet this contingency. For example, if a 0·5-gr. sample of high magnesian hydrated lime were taken, the solution diluted to 500 ml., and a 50-ml. aliquot portion taken, the result calculated from the equation would have to be multiplied by 10, since 50 ml. would represent 0·05 gr. of the sample. While it may seem that such a small amount of the sample

would lead to large errors, the author has not found it so. With such dilutions the author has determined the MgO content of dolomitic lime as accurately as with the gravimetric method.

New Plant to Increase Cement Production.

The methods adopted to increase the output at a works of the Calaveras Cement Company have been described in our United States contemporaries. The improvements include the installation of new classifiers, clinker coolers, two

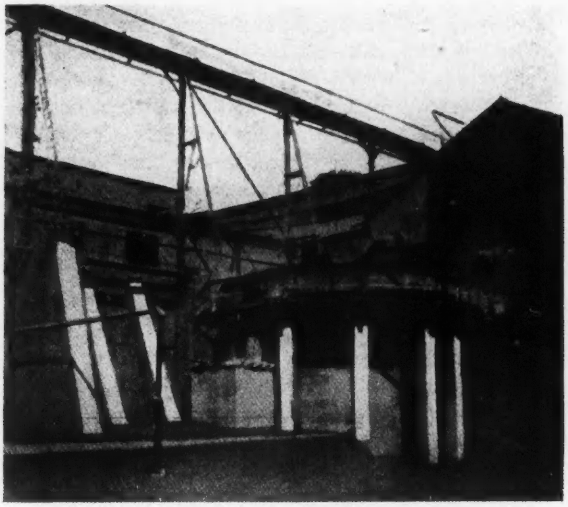

Fig. 1.—Bowl Classifier.

tertiary crushers that follow the primary gyratory and two 10in. secondary mills, and the use of feedoweights to control the feed to the compartment mills.

Crushed rock is prepared by a 42in. gyratory crusher, two 10in. fine grinding mills, and two new tertiary crushers which provide an ample capacity of minus 1in. raw feed. The new crushers have a capacity of 35 tons per hour with 85 per cent. passing ¾in. There are two complete raw grinding closed circuits, one for each of the two wet process kilns. Crushed rock is moved by belt conveyor passing through a feedoweight which records the quantity ground and keeps a

maximum steady feed to the 8ft. by 7ft. by 16ft. two-compartment ball mills. The crushed stone is fed to the primary compartment of the mill where the product is taken from the mill sumps and pumped to two vibrating screens. Underflow from the screens passes to a bowl classifier (Fig. 1) and the overflow is returned to the primary compartment of the mill for further grinding. Rakes (Fig. 2) remove the sands from the bowl classifier, and these flow by gravity to the secondary compartment of the ball mill. The product of the secondary compartment is returned by pump from the mill sump to the bowl classifier.

Overflow from the bowl classifier is pumped to a thickener where the water content is reduced to about 35 per cent. before the slurry is pumped to the blending tanks for kiln feed. Slurry from the blending tanks is fed to the kilns by the customary ferris wheel equipment.

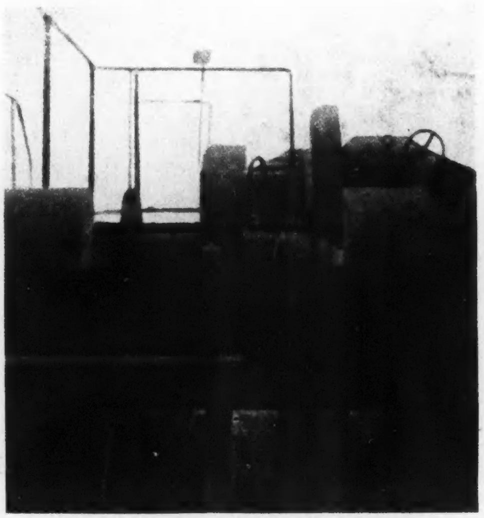

Fig. 2.—Bowl Classifier Rakes in Operation.

The new raw grinding arrangement and the additional classifying equipment have worked out very satisfactorily. Grinding water was increased from 35 per cent. to 85 per cent., and mill output was increased materially. Fineness of grinding was increased from 88 per cent. through a 200-mesh sieve to more than 95 per cent. passing 200-mesh sieve. Beneficial results also have been noted in the kiln operation due to the increased fineness and the blending effect of the slurry reserve in the 150ft. thickeners.

In the kiln department a clinker cooler has replaced the old rotary cooler. The new cooler serves one of the two gas-fired 11ft. 3in. by 10ft. by 240ft. kilns. The total annual output is approximately 233,000 tons. Clinker leaving the cooler has a temperature of 220 deg. F. With the new cooler an increase in kiln capacity has been noted. The air-quenched clinker also has been found to grind much easier in the finish mills.